GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[x] ORIGINAL [ ] REVISION NO. ______

Project No. A-3046 — DATE 9/18/81

Project Director: Mr. T. A. McFadden — ~~School~~/Lab EML/RSD

Sponsor: U. S. Army Missile Command; Redstone Arsenal, AL 35898

Type Agreement: Delivery Order No. 0029 under Contract No. DAAH01-81-D-A003

Award Period: From 8/28/81 To 10/31/81 (Performance) 12/31/81 (Reports)

Sponsor Amount: $15,000 — Contracted through:

Cost Sharing: None — GTRI/~~GIT~~

Title: Checkout Procedure for Anechoic Chamber

ADMINISTRATIVE DATA

OCA Contact Duane Hutchison x4820

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Defense Priority Rating: DO-A2 under DMS Reg. 1

Security Classification: Unclassified

RESTRICTIONS

See Attached Government Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Government; except that items costing less than $1,000 vests with GIT if prior approval to purchase is obtained from the Contracting Officer.

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FORM OCA 4:781

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date 2/18/82

Project Title: Checkout Procedure for Anechoic Chamber

Project No: A-3046

Project Director: T. A. McFadden

Sponsor: US Army Missile Command

Effective Termination Date: 10/31/81

Clearance of Accounting Charges: 12/31/81

Grant/Contract Closeout Actions Remaining:

- [x] Final Invoice ~~and Closing Documents~~
- [ ] Final Fiscal Report
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- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
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FORM OCA 10:781

A-3046

Monthly Technical Report No. 1
and
Monthly Cost and Performance Report No. 1

Report Period
September 1 through September 30, 1981

ANECHOIC CHAMBER

T. A. McFADDEN/J. L. Dickens

Contract No. DAAH01-81-D-A003
Delivery Order No. 0029
Project No. A-3046

Prepared for

U. S. Army Missile Command
Attn: DRSMI-IYE/Morris
Redstone Arsenal, Alabama 35898

Prepared by

Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30332

WORK PERFORMED DURING THIS PERIOD

This month marked the first technical performance period in support of DAAH01-81-D-A003, Delivery Order # 29. The purpose of this task is to test the RF reflection characteristics of the Anechoic Chamber in the A-wing basement of building 5400.

Discussions have previously taken place with Dr. Fahey regarding a test method for use in the Chamber. The method suggested requires a collector of test equipment which does not currently exist in the Chamber facility. However, the task of borrowing the necessary test equipment has begun. It is anticipated that all the required test equipment can be borrowed locally for the time necessary to test the Chamber.

PROBLEMS

None

WORK PLANNED

- o Test Chamber
- o Produce data supporting test results

Cost Information

The following charges have been incurred against the contract during period September 1, through September 30, 1981.

	Expended	Encumbered
Personal Services (PS)	$ -0-	$ -0-
Materials and Supplies	-0-	-0-
Travel	-0-	-0-
Retirement (@ 11.11% of PS)	-0-	-0-
Subtotal	-0-	-0-
Equipment	-0-	-0-
Overhead (@ 55% of Subtotal)	-0-	-0-
TOTAL	$ -0-	$ -0-

The breakdown of personal services is as follows:

	Dollars	Approximate Man Hours
Principal Research Scientists/Engineers	$ -0-	-0-
Senior Research Scientists/Engineers	-0-	-0-
Research Scientists II/Engineers II	-0-	-0-
Research Scientists I/Engineers I	-0-	-0-
Technicians/Draftsmen	-0-	-0-
Students	-0-	-0-
Secretarial/Clerical/Other	-0-	-0-
TOTAL	$ -0-	-0-

The current financial status of the contract is as follows:

	Budget As Proposed	Expended	Encumbered	Free Balance
Personal Services (PS)	$ 7,289.10	$ -0-	$ -0-	$ 7,289.10
Materials and Supplies	100.00	-0-	-0-	100.00
Travel and Shipping	255.81	-0-	-0-	255.81
Equipment	2,061.80	-0-	-0-	2,061.80
Overhead	4,590.97	-0-	-0-	4,590.97
Retirement	732.32		-0-	732.32
FUNDING	$ 15,000.00	$ -0-	$ -0-	$ 15,000.00

Based on present full funding, the funding and equivalent man hours are sufficient to complete the task.

FINAL REPORT DAAH01–81–D–A003/0029
PROJECT NO. A–3046

CHECKOUT PROCEDURE FOR ANECHOIC CHAMBER

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

1981

December 1981

Prepared for
U. S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA 35898

FINAL REPORT

CHECKOUT PROCEDURE FOR ANECHOIC CHAMBER

J. L. Dickens
T. A. McFadden
M. H. Thornton

Contract No. DAAH01-81-D-A003
Delivery Order No. 0029
Project No. A-3046

Prepared for:

U. S. Army Missile Command
Systems Simulation Directorate
Redstone Arsenal, AL 35898

Prepared by:

Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30332

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Anechoic Chamber Testing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the work done in testing an Anechoic Chamber to be used as a general purpose laboratory facility for performing open-loop IHAWK missile testing and radome measurements.

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PREFACE

This technical report was prepared by the Electromagnetics Laboratory of the Engineering Experiment Station, Georgia Institute of Technology, for the U. S. Army Missile Command, Redstone Arsenal, Alabama. The contract technical manager was E. E. Evers (DRSMI-RDF). Report authors are T. A. McFadden, J. L. Dickens, and M. H. Thornton. The purpose of this report is to document the testing of an Anechoic Chamber Facility.

Detailed documentation on the chamber was published in the final report of a related task, "IHAWK Digital Avionics and Integrated Guidance Concept," Contract DAAH01-81-D-A003, Delivery Order 0013.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U. S. Army Missile Command.

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1.0 INTRODUCTION

The anechoic chamber, located in the A-wing basement of building 5400, is to be used for radome measurements and boresight error measurements on various missile systems. The dimensions, construction and layout of the chamber, and particularly, the installation of the Georgia Tech radome positioner was described in the final report for Delivery Order 0013, titled "IHAWK Digital Avionics and Integrated Guidance Concept."

Reflections from anechoic chamber walls have been shown to degrade boresight measurements (1, 2, and 3), thus, there was a need for tests of the A-wing chamber's reflection characteristics. No information was found on the construction of the chamber. The chamber was installed more than seven years ago, and no information could be found characterizing the absorption materials or describing the performance of the chamber.

2.0 DESCRIPTION OF TEST CONFIGURATION

It is a well known fact that chamber measurements are degraded by energy from four specular spots on the two side walls, floor and ceiling. In order to measure the degradation, the energy reflected from each specular path was compared to the straight through path. The straight through path is defined as the path directly down the middle of the chamber from the transmit antenna to the receive antenna with the antennas pointing directly at each other. In the reflected energy measurement both the transmit and receive antenna point at the center of the specular spot. The received power from a specular spot is compared to the received power from the straight through path, and their ratio is expressed as attenuation in decibels.

A measurement technique was recommended by Dr. Fayhe that separates the power received according to path length; thus, power received from a specular point is easily resolved from power received from other "hot spots" in the chamber. One can easily show that the measured power is traveling over a particular path by physically measuring the path length and comparing this length with that obtained by calculations based on the distance between nulls, as will be explained in the following paragraphs.

The technique requires the nulling of a reference signal (R2), Figure 1, from a microwave sweep generator with the test signal reflected off the chamber wall (R1). The variable attenuator is adjusted until the deepest null is obtained at the frequency of interest and the attenuator reading is recorded. The following three paragraphs explain the nulling process. Next the transmit and receive antennas are pointed directly at each other and the nulling adjusting process is repeated. In this measurement there is no loss due to reflection from any surface in the chamber. The difference in the attenuator readings in these two measurements is the attenuation due to reflection from the chamber wall.

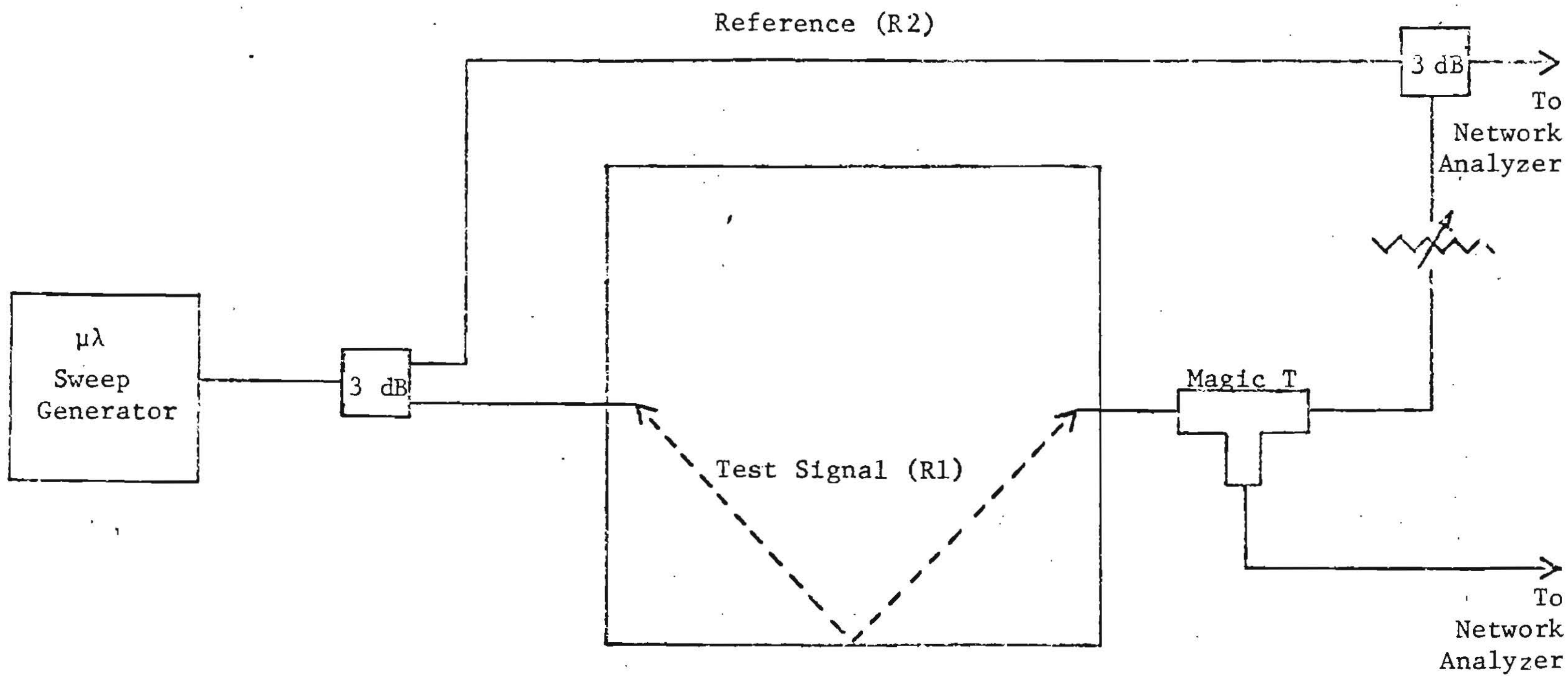

Figure 1. Anechoic Chamber Signal Paths.

In the configuration shown in Figure 1, a network analyzer is used to measure the relative power of the summed signals from the magic T to that of the reference signal. The amplitude (A) of the summed signals can be expressed as the sum of two sinusoid signals,

$$A = K_2 \cos (\omega t) + K_1 \cos (\omega t + \frac{2\pi \ \Delta D}{\lambda}) \tag{1}$$

where K_1 and K_2 are the peak amplitudes of the two signals; ω is the angular frequency of the signals in radians per second, and the phase difference of the two signals is, $\frac{2\pi \ \Delta D}{\lambda}$

where Δ D is the difference in path length of the two signals R1 and R2, and λ is the wavelength.

The absolute amplitude of A which is the parameter measured by the network analyzer is expressed by,

$$|A| = \sqrt{K_1^2 \ K_2^2 + 2K_1K_2 \cos (\frac{2\pi \ \Delta D}{\lambda})} \tag{2}$$

If one plotted the absolute magnitude of A versus time or observed $|A|$ on the oscilloscope used in the test configuration shown in Figure 2, one would see notches. These notches occur at multiples of $2\pi m$ wavelengths. The arguments of the two cosine square terms provide the following equation for the location of these nulls:

$$\frac{2\pi \ \Delta D}{\lambda} = m\pi; \quad m = 1, 3, 5 \ldots \tag{3}$$

Note: Equipment Identified in Table 1.

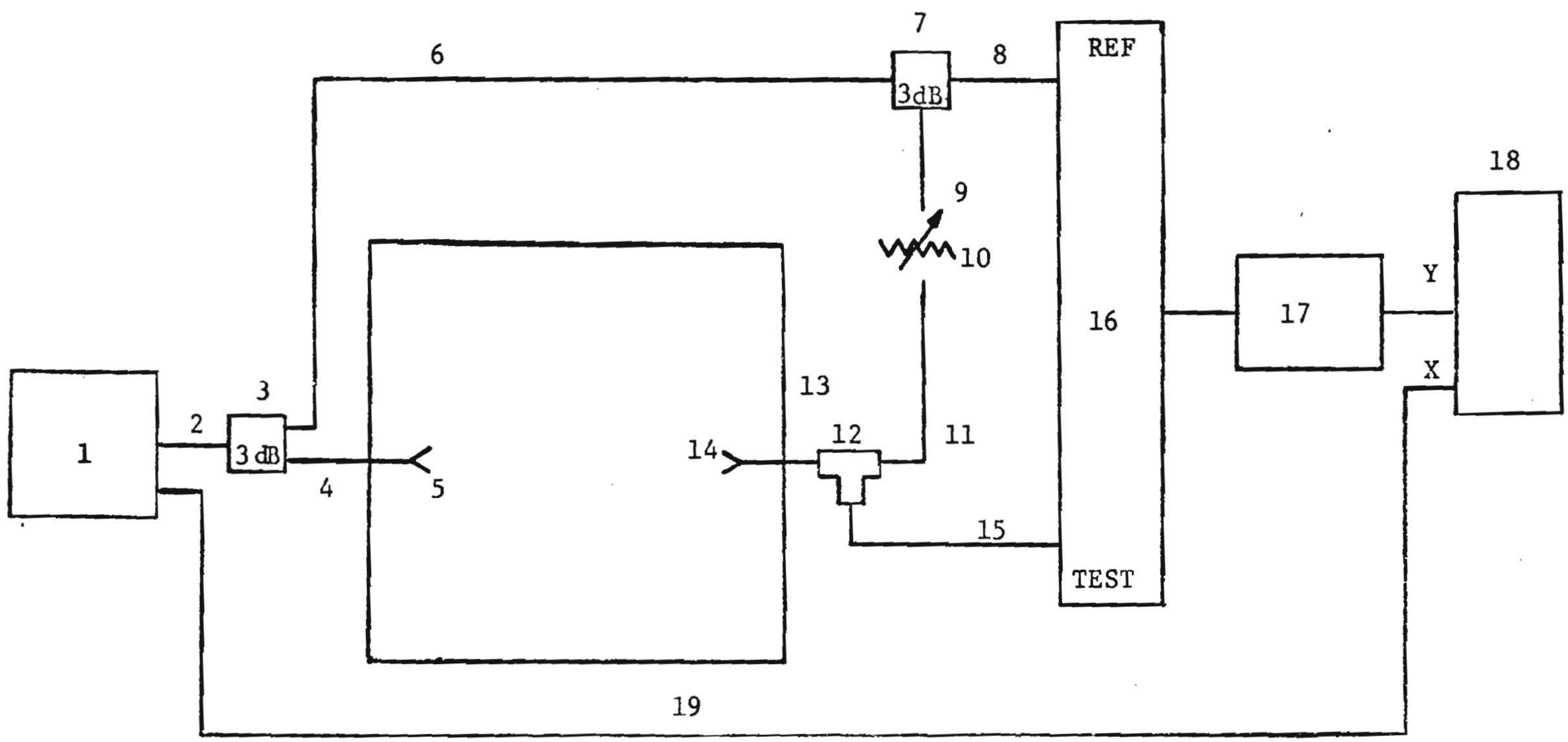

Figure 2. Overall Anechoic Chamber Test.

Table 1

TEST EQUIPMENT LIST

ITEM #	DESCRIPTION
1.	8690A sweep oscillator with 869H4 plug-in 8-12.4 GHz
2.	.0865 semi rigid coaxial cable 6.5 inch with SMA cable plugs
3.	Power splitter 3 dB 2-18 GHz Omni-Spectra 2090-6205-00
4.	RG-142 flexible coaxial cable 15 feet with right angle SMA cable plugs
5.	Slotted antenna array 27 dB X-band
6.	RG-142 flexible coaxial 40 feet with straight SMA cable plugs
7.	Power splitter 3 dB 8-12 GHz Merimac PDM-22-106
8.	RG-142 flexible coaxial 1 foot with right angle SMA cable plugs
9.	.0865 semi rigid coaxial cable 6.5 inch with straight SMA cable plugs
10.	Variable attenuator, 0-50 dB, HP X382A 8.2-12.4 GHz
11.	RG-142 flexible coaxial cable 1 foot with right angle SMA cable plugs
12.	X-band hybrid tee
13.	RG-142 flexible coaxial cable 5 feet and 9.5 inch
14.	Hawk antenna with Georgia Tech modified waveguide to coaxial adapters
15.	RG-142 flexible coaxial cable 10 feet 10.75 inch
16.	Harmonic frequency coverter HP 8411A 110 MHz-18 GHz
17.	Network analyzer HP 8410B 110 MHz-18 GHz
18.	Oscilloscope Tektronix SC504 80 MHz
19.	RG-58 flexible coaxial cable 40 feet

Equation (3) will be used to verify that the energy measured while pointed at a particular specular point is coming from that point and not from some other hot spot in the chamber. This verification is accomplished by showing that the difference in path lengths between the straight through path and reflected path correspond with the change in width between nulls as expressed in Equation (3).

When the attenuator is adjusted for maximum depth in the notches, the two inputs into the magic T are equal in amplitude and cause maximum cancellation. The attenuation due to reflection from a surface area under test is simply the difference in attenuator readings obtained from the straight through path measurement and the reflected path measurement. The reference signal (R2) remains constant through both measurements. The parameters that change are the path length indicated by null spacing and the amplitude of signal (R1). Figure 2 shows the equipment configuration in more detail and cable lengths for the test. To produce the power versus frequency plots referred to in later paragraphs the oscilloscope (18) is replaced by an X-Y recorder. Figures 3 and 4 provide the path lengths and angles involved in the side wall reflections and floor-ceiling reflections, respectively. These data will be used to verify the chamber measurements obtained.

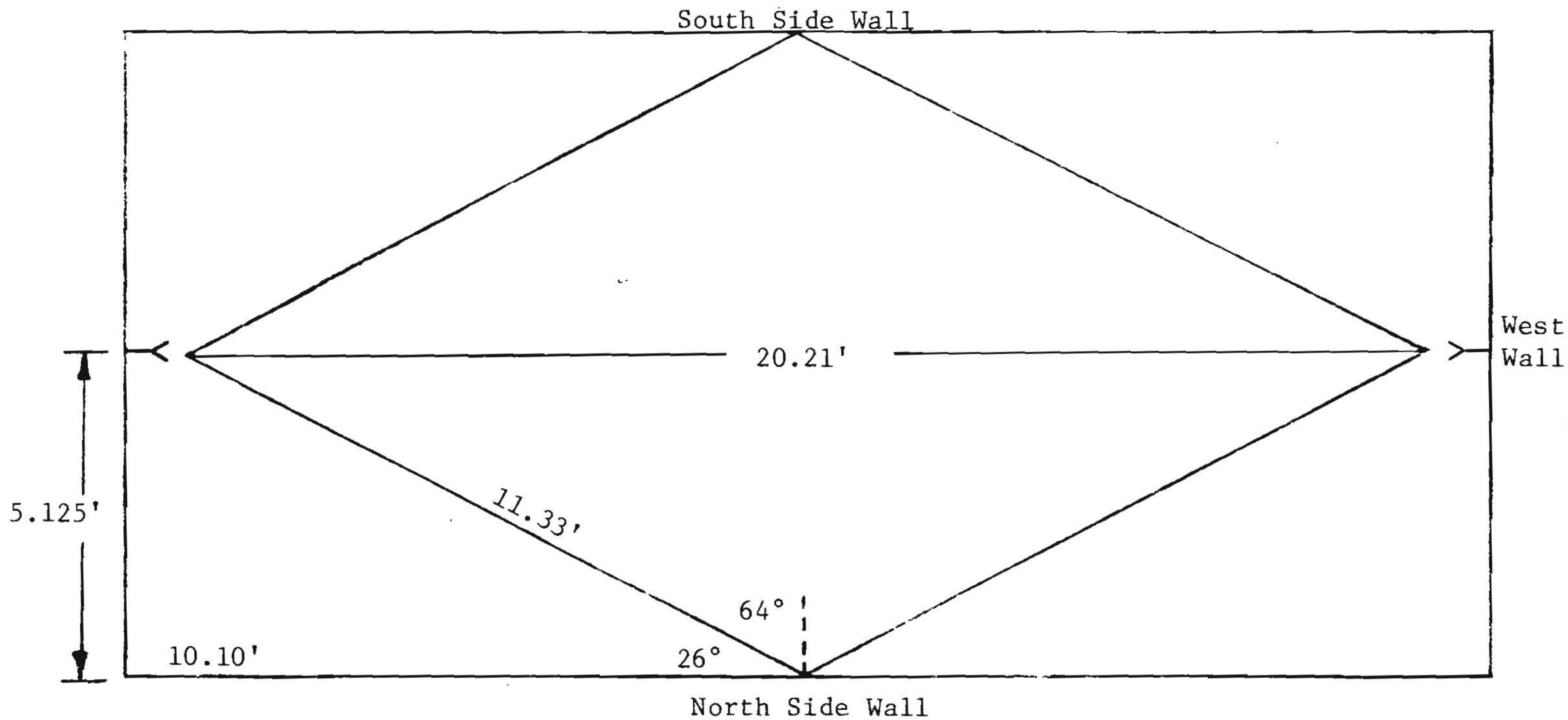

Figure 3. Top View of Chamber.

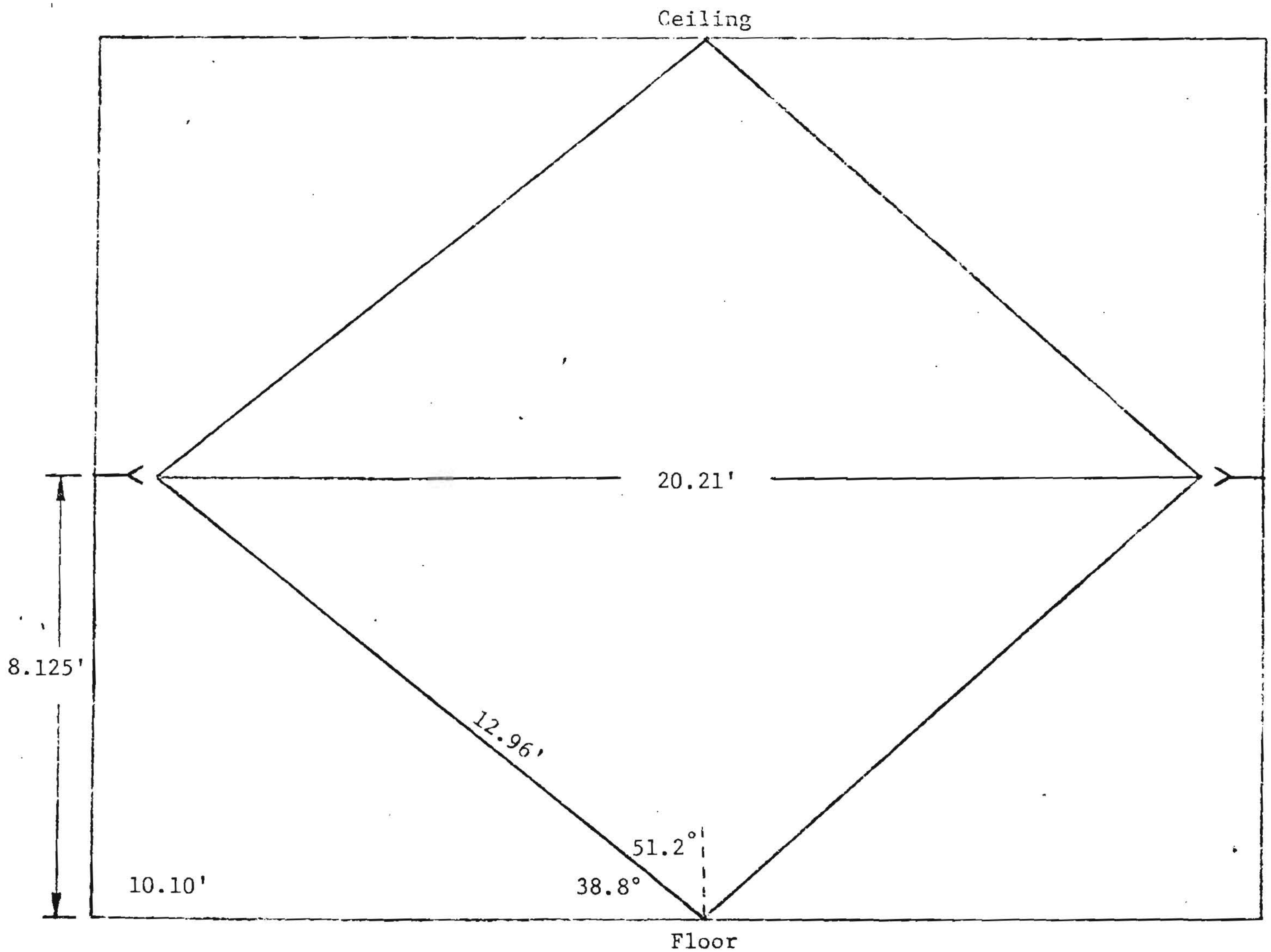

Figure 4. Side View of Chamber.

3.0 RESULTS OF MEASUREMENTS

When measuring the direct through path, the deepest nulls were obtained with the attenuator set to 0.0 dB, and as can be seen by Figure 5, the frequency change (Δf) between the deepest nulls is 50 megahertz.

With the aid of Equation (3) and the substitution,

$$\lambda = \frac{c}{f} \tag{4}$$

we obtain, for the change in distance ΔD between the first 2 nulls,

$$\Delta D = \frac{c}{\Delta f}$$

thus,

$$\Delta D = \frac{3 \times 10^8}{5 \times 10^7} = 6 \text{ meters.} \tag{5}$$

These data for the straight through path are used as a reference in all the following tests.

Next, for the north sidewall measurement, the attenuator was set to 23 dB when the deepest nulls occurred. From Figure 6, which is the power versus frequency plot obtained from the reflections from the north sidewall, the Δf between the deepest nulls is 54 megahertz. Referring to Figure 3, the difference in path length between the straight through path and the path while reflecting off the north wall is $\Delta D = 6.0 - 0.75 = 5.25$ meters. Then $\Delta f = 57.1$ megahertz from Equation (5). The verification of the location of the source of the reflected energy is accomplished by comparing Δf measured from the X-Y plot to the Δf calculated from ΔD. The percentage of error between the calculated and measured Δf is

$$\%\ \text{error} = \frac{57.1 - 54}{57.1} \times 100 = 5.4\% \tag{6}$$

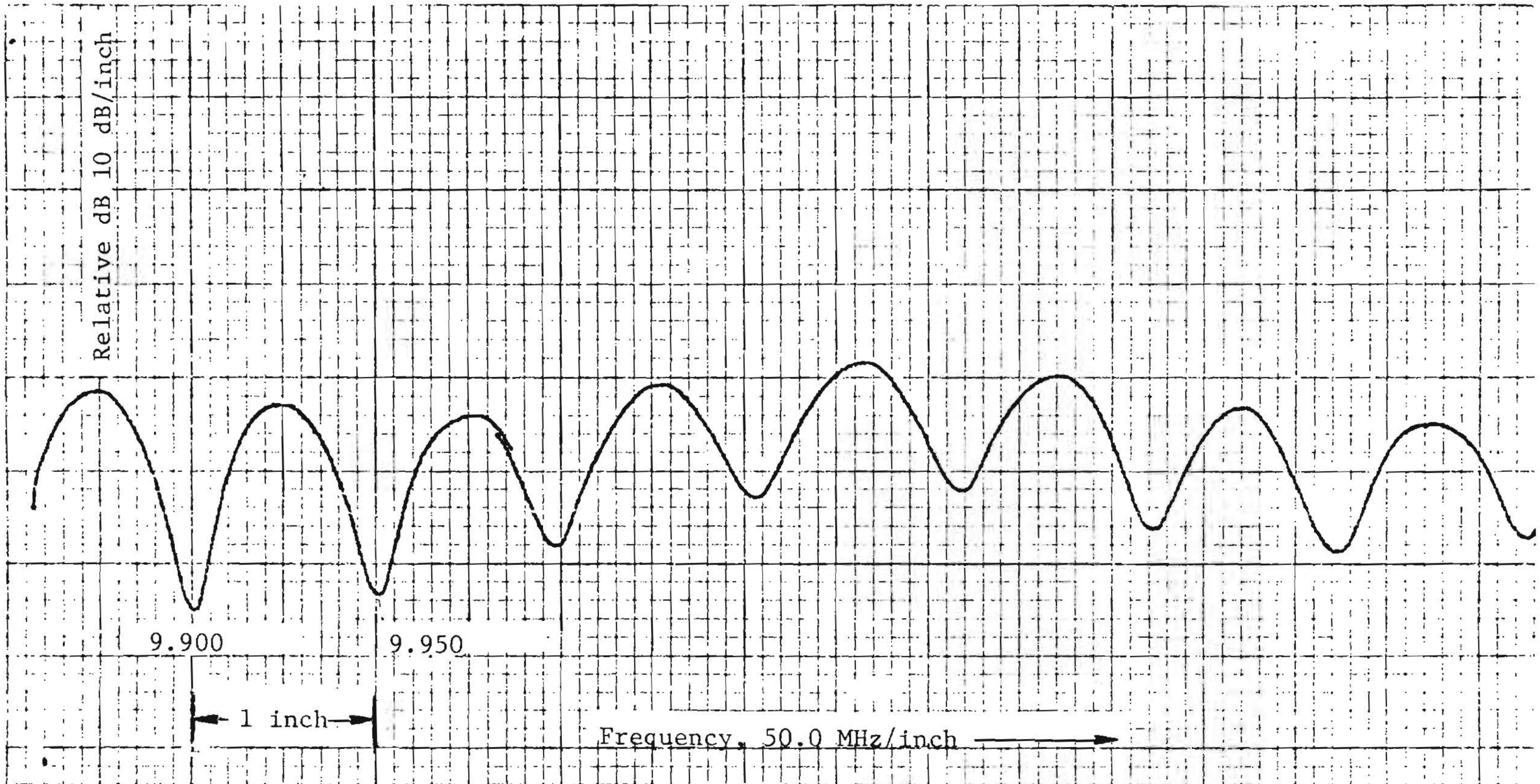

Figure 5. Straight Through Path.

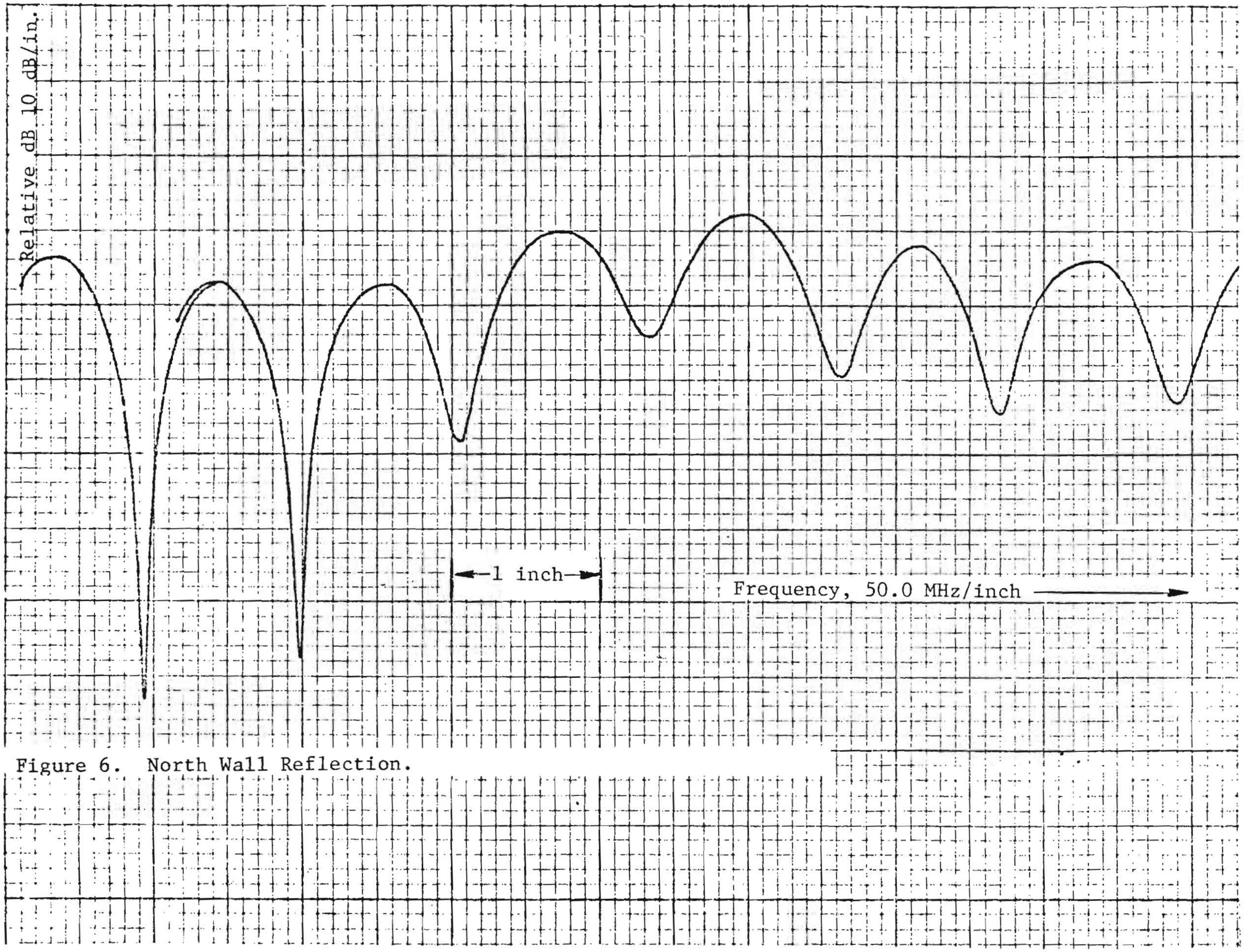

Figure 6. North Wall Reflection.

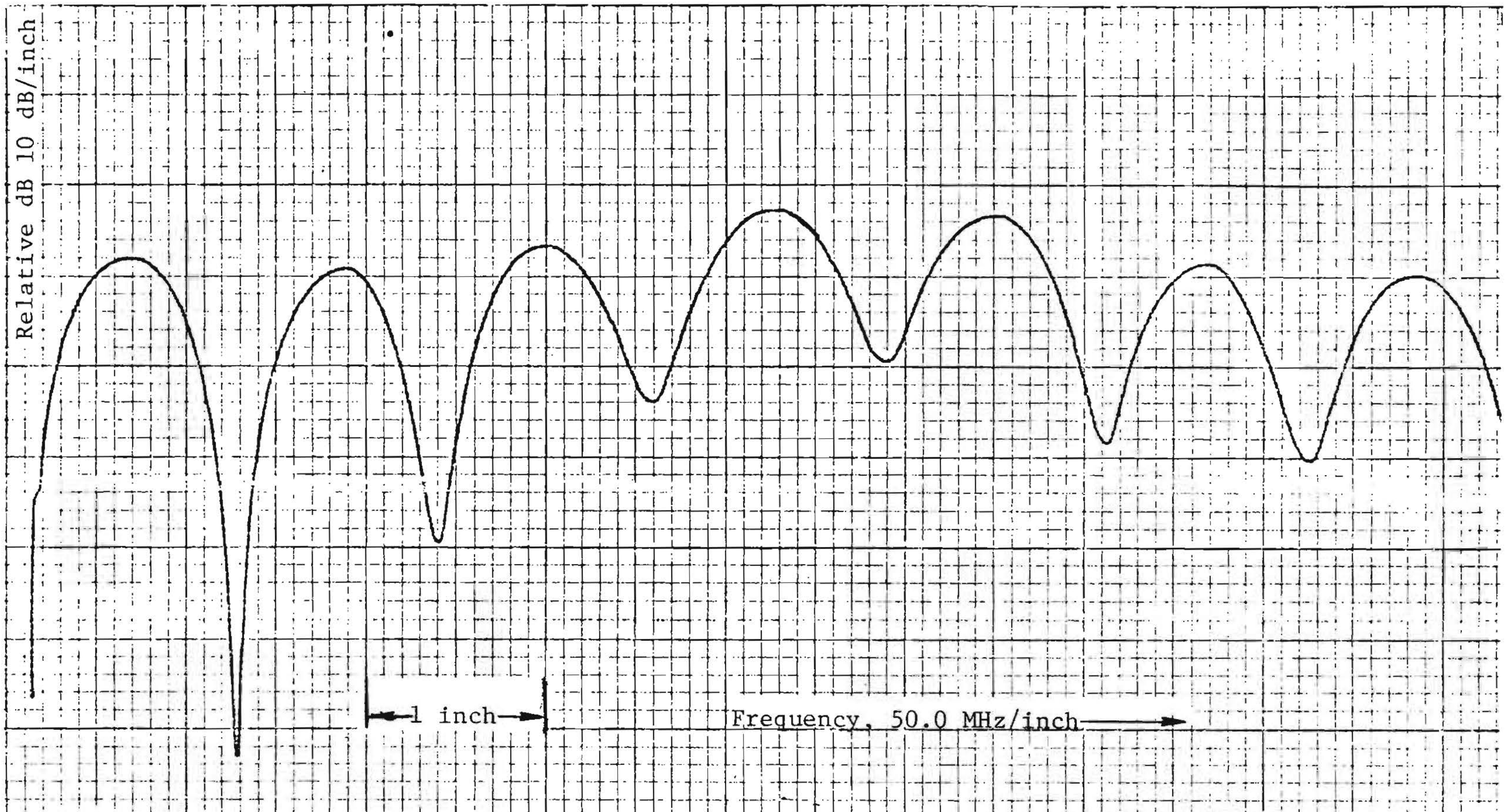

Figure 7. South Wall Reflection.

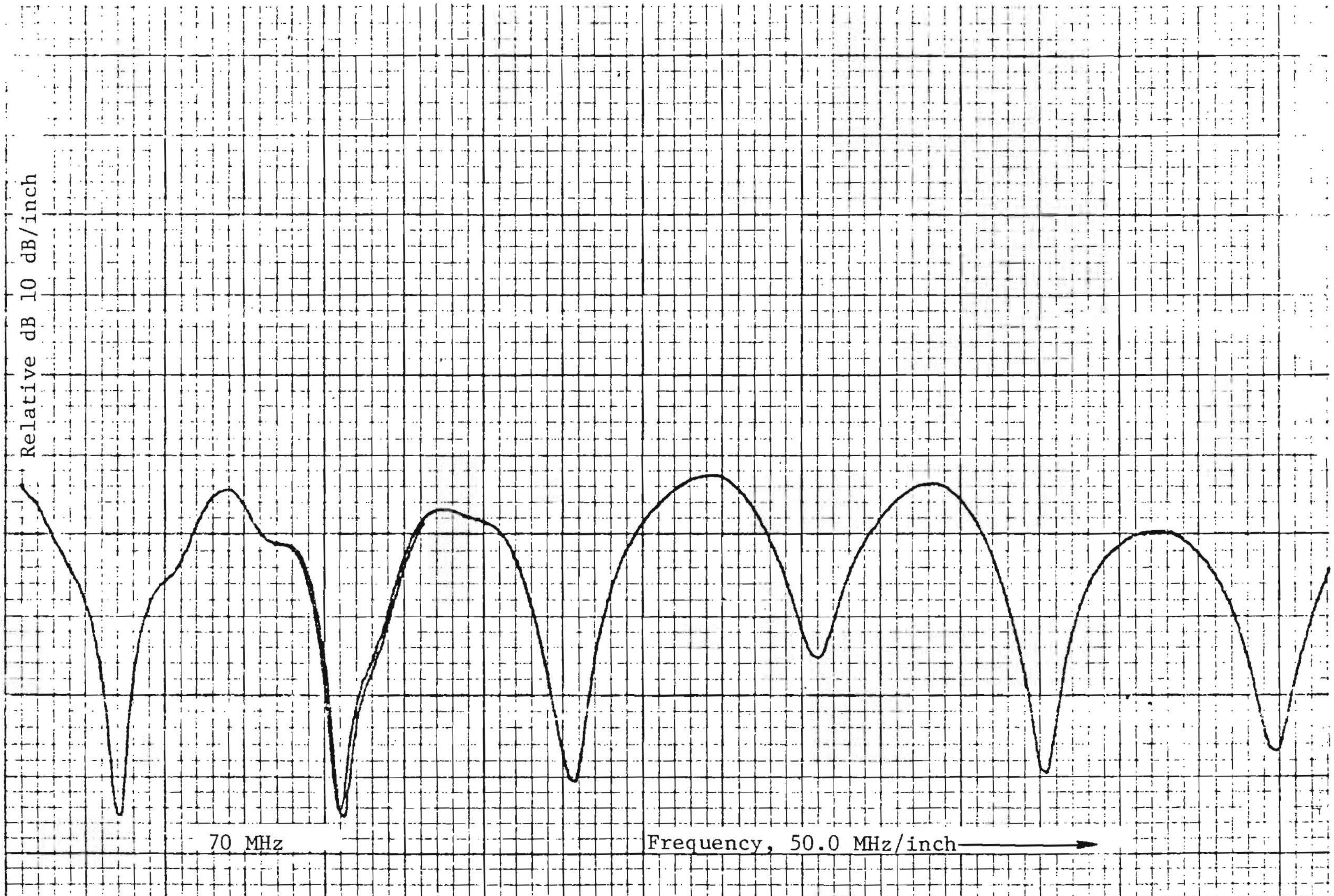

Figure 9. Floor Reflection.

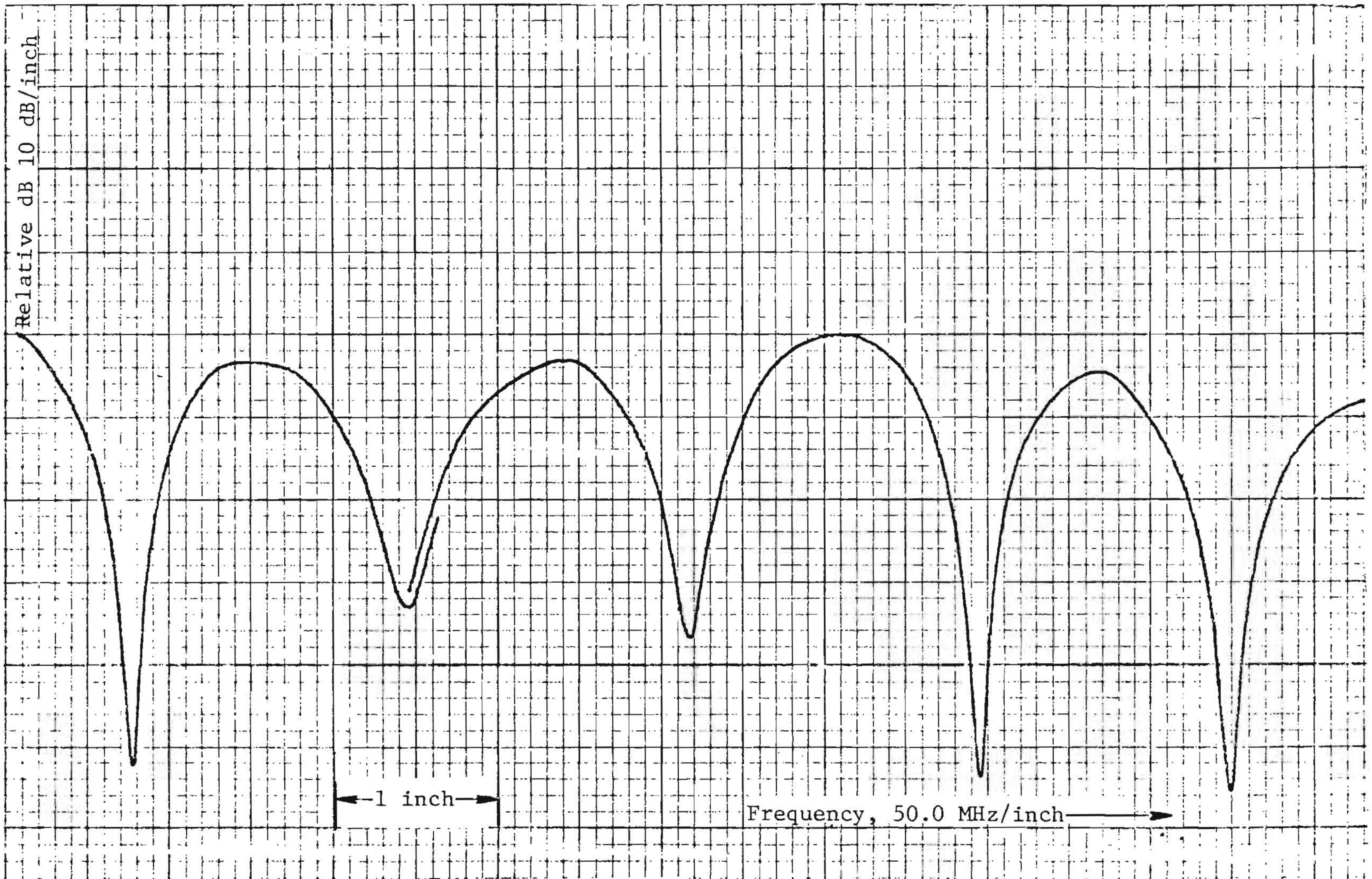

Figure 8. Ceiling Reflection.

The error path is linearly related to Δf. Hence, the path length error is 0.28 meters which is insignificant in comparison to the path length differences expected from hot spots in the chamber.

Figures 7, 8, and 9 show the frequency versus amplitude plots for the remaining specular points: the south sidewall, ceiling, and floor, respectively.

Table 2 summarizes the absorption measurements from each specular point and the measured and calculated frequency shifts between the deepest nulls. Again, the Δf data shows that the path lengths measured in the chamber correspond to the path length caluclated from the frequency null points. This adds credence to the absorption values obtained. The ceiling path length values obtained are not as solid as the other values obtained. Due to the height of the chamber and the shifting nature of the flooring, the actual path length and reflection angles were not measured for safety reasons. The path length was assumed to be equal to that obtained from the floor measurements because of the symmetry of the room. This can be seen in Figure 4. The transmit and receive antennas are centered vertically in the east and west walls. The antennas were positioned by setting in gimbal angles equal but oppposite in sign from the floor measurements. The results are obviously not perfect, as can be seen in the 6.5 percent error in Δf. However, this error does not indicate a gross error in the absorption factor.

Table 2

ABSORPTION FIGURES FOR ANECHOIC CHAMBER HOT SPOTS

Specular Point	Absorption dB	Δf Measured MHz	Δf Calculated MHz	Improved Absorption dB
North Wall	23.0	54.0	57.1	28.0
South Wall	20.0	58.0	57.1	25.0
Ceiling	25.5	75.0	70.4	20.5
Floor	33.5	70.0	70.4	33.5

Two 1 x 3 foot pieces of the anechoic chamber absorption material were tested by the RANTEC Division of the Emerson Electric Company. Reflection coefficients were recorded in decibels. These data are shown in Table 3. However, the incident angles recorded are only marginally useful. The ceiling and floor incident angles in the chamber are 51 degrees, which is just outside of the RANTEC recorded data points. If one interpolates between the 10.0 and 10.2 gigahertz data points to 10.125, a reflection coefficient of 27.0 dB is obtained. This value is reasonably close to the 25.5 dB recorded for the ceiling. It should be pointed out that the floor material is of a different construction than the walls and ceiling, and it has a higher absorption coefficient at 10.125 gigahertz. No conclusion can be reached about the sidewall performance from the RANTEC data because the incident angle was 64 degrees, 14 degrees outside of the range of measured angles.

Table 3

MEASURED DATA ON PYRAMIDAL CHAMBER MATERIAL

Angle 1	Reflection Coefficient in dB: 10.0 Gigahertz, Horizontal Polarization	10.0 Gigahertz, Vertical Polarization	10.2 Gigahertz, Horizontal Polarization	10.2 Gigahertz, Vertical Polarization
10	20	29	18	26.5
20	25.5	37	22	27.5
30	29	32.6	25	39
40	33.4	40	32.8	43
45	34	45	34.5	42
50	33.8	24.5	37.5	28.5

4.0 ANALYSIS OF BORESIGHT ERRORS

When testing monopulse antennas, a boresight error is produced due to sidewall reflections. This Boresight Error (BSE) expressed in milliradians is given by (1, 2, and 3),

$$BSE = \frac{2000R}{\pi L} \left[\frac{1 - \cos (KL \sin \Theta_r)}{L \sin \Theta_r}\right] \tag{7}$$

Where L is the test antenna size in wavelenths, Θ_r is the angle of arrival of the reflection, and R is the reflected ray/direct ray voltage ratio. Plugging in the values for the most expected configuration in the A-wing chamber, and using $\Theta_r = 26^o$ and $R = 0.1$ for the worst case sidewall data from Table 2, a maximum BSE = 0.247 milliradians is obtained.

5.0 CONCLUSIONS

The boresight errors induced by a "good radome" are 1-10 milliradians (4). BSE for "medium radomes" are 10-20 milliradians and greater than 20 milliradians for "poor radomes." Thus, BSE from the worst case wall reflections in the A-wing chamber will be 25 percent of the very best radome error expected.

To further improve the performance of the A-wing chamber, the specular points on the ceiling, walls and floor have been covered with a layer of ECCOSORB CV-4. This modification reduced the sidewall reflection by approximately 5 dB. When plugged into Equation (7) a maximum BSE of 0.14 milliradians was obtained. In Table 2 the rightmost column indicates the expected chamber performance with this new absorber material.

Further steps could be taken to limit reflections from the specular points, such as reducing the sidelobe level of the transmit antenna in the direction of the specular points, and minimizing the transmitted beamwidth consistent with far-field and amplitude taper criteria. However, this type of modification would reduce the frequency bandwidth over which the anechoic chamber could be used.

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2. Hanson, R. C., Gotkis, S. J., and Root, L. W., IEEE "Sidewall Induced Boresight Error in An Anechoic Chamber," Trans. on Aerospace and Electronics Systems, November 1971.

3. Schuchardt, J. M., Kozakoff, D. J., Gallentine, D. O., and Long, T. N., "Automated Radome Performance Evaluation in the Radio Frequency Simulation System (RFSS) Facility at MICOM," 15th Symposium on Electro-Magnetic Windows, Georgia Institute of Technology, Atlanta, Georgia, June 1980.

4. Bird, R. W., Kozakoff, D. J., and Schuchardt, J. M., "Design and Fabrication of a Radome Measurements Receiver," Final Report on Project A-2314, prepared for U. S. Army Missile Research and Development Command, Redstone Arsenal, Alabama, Contract No. DAAK40-78-D-008, Work Order 0008, October 1979.